Integrated Regional and Urban Seismic Monitoring ¾ Wasatch Front Area, Utah, and Adjacent Intermountain Seismic Belt
04HQAG0014 (October 1, 2003–September 30, 2004)

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Investigations Undertaken (October 1, 2003 – September 30, 2004):

The cooperative agreement identified here, combined with funding from the State of Utah, provided major support for the operation of (1) the University of Utah Seismograph Stations' (UUSS) regional and urban seismic network and (2) a regional earthquake-recording and information center on the University of Utah campus in Salt Lake City.

At the end of September 2004, UUSS operated and/or recorded 204 stations (50% short-period, 35% strong-motion, 15% broadband). USGS support is focused on the seismically hazardous Wasatch Front urban corridor of north-central Utah, but also encompasses neighboring areas of the Intermountain Seismic Belt. During the report period, project efforts involved: (a) continued development of a real-time earthquake information system in the Wasatch Front area as an element of an Advanced National Seismic System (ANSS); (b) timely study of new data acquired with our modernized network; (c) ongoing network operations; and (d) miscellaneous related activities.

Results:

Real-Time Earthquake Information System. During the past four years, we have successfully (1) integrated weak- and strong-motion monitoring within a modernized regional/urban seismic network and (2) developed an effective real-time earthquake information system in advance of the 2002 Salt Lake City Winter Olympics. In FY 2004, no new ANSS instrumentation was allocated to our network because of stagnant ANSS funding. Efforts were intentionally focused on making our real-time information system more robust. Accomplishments in FY 2004 included the following:

- *Earthworm ¾* Our 13-machine Earthworm system (hardware and software) for real-time earthquake monitoring and automated alerts is in a constant state of development and is fragile. Work done on this system during FY2004, in addition to routine maintenance and monitoring of the system performance, included: modifications to accommodate new stations and changes in instrumentation and/or telemetry at existing stations; transfer of Earthworm software for K2 strong-motion instrument telemetry from multiple PCs to a SUN workstation; and progress towards completing the installation of Earthworm v6.2. Earthworm v6.2 is now running on all of our Earthworm machines except for (1) the PC which digitizes data from analog telemetry stations and (2) the machines on the primary system which interact with the

Oracle database. Our testing and configuration of Earthworm v6.2 on the latter machines was delayed for more than a year by a bug in the Earthworm database software. The bug was finally fixed by David Kragness, a software consultant to the USGS, during the last month of the report period

- *ShakeMap* ¾ We continued to implement ShakeMap and customize it for use in the Wasatch Front urban corridor. We also worked with the ShakeMap Working Group, contributing code. During FY2004, four ShakeMaps were generated and posted to our Web site. Two of these were automatically processed and two manually. The two that were manually processed were too close in time to the first event in a sequence to be accurately discriminated. ShakeMap developments included fully incorporating FY2003 stations, upgrading our in-house user's manual, adding a third USGS server to our transfer list, and installing and testing the new version 3.0 on our backup machine. Major efforts were directed towards generating and posting scenario earthquake ShakeMaps to our Web site. Scenarios were posted for two events: (1) an M7 earthquake on the Salt Lake City segment of the Wasatch fault and (2) an M7 earthquake on the Brigham City segment of the Wasatch fault. The Salt Lake City segment scenario was a central theme in an article for City Weekly (a local weekly circular). The Brigham City segment scenario was developed and used for a Utah Geological Survey earthquake preparedness training exercise. Results of the scenario were automatically emailed to the exercise participants at a prescribed time and posted to the UUSS Web site, mimicking the procedure following a real earthquake. During FY 2004 we also met with the Utah Department of Emergency Services and a FEMA representative to plan for the next stage of ShakeMap developments in Utah. Both agencies expressed the desire (1) that ShakeCast be installed so that ShakeMaps can automatically be incorporated into HAZUS, and (2) that ShakeMap coverage be expanded to the entire state of Utah. We have completed the initial planning to meet these two requests.

- *Urban Strong-Motion Stations* ¾ In FY 2003 we received ANSS equipment and funds for adding ten stations to Utah's real-time urban strong-motion network in the Wasatch Front urban corridor. Final installation of three of these stations was completed in October and November 2003, bringing our network total of ANSS strong-motion stations to 75. No new Utah ANSS stations were funded in FY 2004. Considerable effort went into stabilizing digital-radio subnets within our real-time urban network that use Time Division Multiple Access (TDMA) technology and into beta testing REF TEK software. Performance problems with the TDMA subnets were finally resolved by replacing routers with terminal servers at point-to-multipoint telemetry nodes. To reduce telemetry costs, frame-relay telephone circuits at seven strong-motion stations were replaced by either digital radio telemetry or newly available and less expensive DSL lines. We continued to record real-time data streams from four strong-motion stations operated in the Wasatch Front area by the USGS National Strong-Motion Program (NSMP). In addition, we use an import protocol to automatically receive from NSMP both parametric data (in XML format) and waveform data from other NSMP strong-motion stations in the Wasatch Front area that have telephone connections to Menlo Park, CA. The NSMP data usefully contribute to our ShakeMap database.

Miscellaneous Network-Related Studies

- *Triggered Seismicity following the Denali fault, Alaska, earthquake* ¾ Following the Denali fault, Alaska, earthquake on November 3, 2002, the University of Utah's regional seismic network recorded an abrupt increase in local microseismicity during the first 24 hours (>10 times the average background level), beginning with the arrival of the surface waves; elevated seismicity continued for tens of days throughout much of Utah's main seismic belt. The Denali fault earthquake triggered seismicity not only in Utah, but also throughout much of the western United States. During FY 2004 a manuscript describing the observations made in Utah was prepared and submitted to the Bulletin of the Seismological Society of

America (Pankow et. al., 2005). After revision, the manuscript was accepted for publication in the upcoming special volume on the Denali fault earthquake. In addition to the paper, we also generated an accompanying electronic supplement that contains the earthquake catalog we used in our analysis. A second, related, study that we participated in was a regional analysis of the peak dynamic stresses in the western United States from the Denali fault earthquake and the role of source directivity in enhancing these stresses. This study has also been accepted for the special volume on the Denali fault earthquake (Velasco et. al., 2005).

- *Receiver Function Analysis* ¾ In collaboration with a University of Utah graduate student and others, we have been analyzing teleseismic earthquakes recorded by both regional broadband instruments and the ANSS urban strong-motion network. The student (now a post-doc) has been migrating these data to image crustal/upper-mantle structure. Preliminary results were presented at the 2003 Fall AGU meeting (Sheng et al., 2003) and a paper on this work is in preparation.

- *Coal-mining-induced seismicity* ¾ We continued studies of seismicity induced by underground coal mining in east-central Utah (Arabasz et al., 2004, 2005) in order to serve the needs of (1) mining engineers and mine operators concerned with mine safety and (2) decision-makers dealing with the potential hazards of mining-induced seismicity (MIS) to off-site structures and facilities. The studies involved cooperative research with the USGS and the U.S. Bureau of Reclamation, including ground-motion studies of the MIS in order to evaluate the hazard of surface ground shaking and the estimation of probable maximum magnitude of MIS for engineering use. During FY 2004 we began partnerships with three coal mines in Utah's Book Cliffs mining district. Above each mine, we cooperatively installed one 4-component seismograph (3-component accelerometer plus a vertical-component short-period velocity sensor) with continuous telemetry to our network operations center. The instrumentation provides mine operators with continuous Webicorder records online, improved locations of MIS at the mine sites, and ground-motion data for the larger events.

Accomplishments in Ongoing Network Operations. Noteworthy accomplishments during the report period included the following:

- *Revision of coda magnitudes in the UUSS catalog, 1981-2002.* As part of a major project to correct systematic time-dependent coda-magnitude (M_C) errors in the UUSS earthquake catalog, 1981-2002, we measured additional signal durations for 4,238 earthquakes in this catalog for which less than three such measurements were available from stations with known gains. We tried unsuccessfully to measure additional signal durations for nearly 1,500 other earthquakes. This work was necessary because the gain corrections we began routinely applying to our duration measurements in 2003 are sometimes unstable, and this problem is difficult to recognize for earthquakes with less than three duration measurements. Final quality control checks on the revised M_Cs are under way.

- *Near-real-time data exchange with other networks* ¾ Throughout the report period, we continued to exchange waveform data in near-real-time with the National Earthquake Information Center, the Idaho National Engineering and Environmental Laboratory, the Montana Bureau of Mines and Geology, Brigham Young University (Idaho), Northern Arizona University, the U.S. Bureau of Reclamation, and the University of Nevada, Reno. These data exchanges are done via the Internet using Earthworm import/export software modules.

- *Assistance to other seismic networks* ¾ Since a meeting in April 2003 with operators of the Puerto Rico seismic network during SSA2003 in San Juan, Puerto Rico, we have been providing technical advice and help on expansion and modernization of their network. During FY 2004 this assistance was in the form of (1) providing technical help for configuring REF TEK-130s, (2) providing examples of response

files in SEED format for common instrumentation, and (3) providing SAC macros for manually determining peak ground accelerations and peak ground velocities from strong-motion data and formatting these measurements for use in ShakeMap. We also provided a customized ShakeMap module for "cancel" to the University of Washington and provided our in-house ShakeMap user's guide to the University of Memphis. Other assistance included remote maintenance of the Northern Arizona University Earthworm system, providing Webicorder displays for newly-installed USGS stations in western Wyoming, and supplying instrument siting contacts for southern Utah to Rick Aster for the RISTRA PASSCAL experiment.

❑ *Archiving waveform data* ¾ All digital waveform data collected by the University of Utah regional seismic network during the report period were submitted to the IRIS DMC in SEED format.

❑ *Submission of earthquake catalog data to ANSS information outlets* ¾ During the report period, Earthworm automatic (non-human-reviewed) hypocenters and magnitudes for earthquakes of magnitude 3.0 and larger in our authoritative regions (Utah and Yellowstone National Park)—2.5 and larger in the Wasatch Front urban corridor—were automatically submitted to the QDDS. Analyst-determined hypocenters and magnitudes for all earthquakes in our authoritative regions were submitted to the QDDS as they were completed, using software that we improved during the report period. These same data were automatically submitted to the ANSS catalog four times per day during the Monday-Friday work week. Events of $M \geq 1.0$ submitted to the QDDS are automatically posted on the ANSS RecentEqs Web pages.

Miscellaneous

❑ *ANSS Implementation Activities* ¾ Besides involvement in the ShakeMap Working Group and helping other seismic networks, we participated in many ANSS implementation activities during FY 2004. Among others, these included coordination of ANSS advisory committees and other planning in the Intermountain West (IMW) Region, service on the ANSS National Implementation and Technical Integration committees, chairing a working group to develop an evolutionary architecture for ANSS, activism in securing Congressional support for increased ANSS funding, and field exploration and noise testing to site a new ANSS national backbone station near Cedar City in SW Utah.

❑ *Utah Earthquake Hazards Working Groups* ¾ In February 2004 we presented two invited talks at a Utah earthquake hazards conference sponsored by the USGS and the Utah Geological Survey and also participated in associated workshops. Four seismologists in our network group are serving on a 15-member Utah Ground-Shaking Working Group, which is planning the development of the next generation of ground shaking hazard maps in Utah. Two are also serving on a Utah Quaternary Fault Parameter Working Group. These activities enable close coordination between our UUSS/ANSS urban strong-motion network and researchers addressing local ground-motion-related issues.

Network Seismicity. Figure 1 shows the epicenters of 1,174 earthquakes ($M_L \leq 3.7$) located in part of the University of Utah study area designated the "Utah region" (lat. 36.75°– 42.5° N, long. 108.75°–114.25° W) during the period October 1, 2003 to September 30, 2004. The seismicity sample includes sixteen shocks of magnitude 3.0 or greater and eighteen felt earthquakes ($2.0 \leq M \leq 3.7$). The largest earthquake within the Utah region during the report period was a shock of M_L 3.7 on December 26, 2003 (17:43 MST) located 12 km (8 miles) southwest of Nephi, UT (epicenter labeled in Figure 1). ShakeMaps were generated using our network data for four earthquakes ($3.4 \leq M \leq 3.7$) during the report period; see *<http:www.seis.utah/shake/archive/>*. Community Internet Intensity Maps were generated by the USGS for eight Utah region shocks; see *<http://pasadena.wr.usgs.gov/shake/imw/archives.html>*.

Non-technical Summary:

This cooperative agreement provides major support for urban and regional seismic monitoring in Utah and neighboring areas. During the report period we operated and improved a real-time earthquake information system in Utah's seismically hazardous Wasatch Front urban corridor. By November 2003, a total of 75 strong-motion stations had been added to our urban network as part of the Advanced National System (ANSS) to meet needs for emergency response and earthquake engineering. More than 1,100 earthquakes were located in our study region during the report period; 16 had a magnitude of 3.0 or larger, and 18 were reported felt. The largest local earthquake was a shock of magnitude 3.7 on December 26, 2003, in central Utah. Many of our activities during the report period were to help build elements of the ANSS in Utah, in the Intermountain West region, and nationally.

Reports and Publications:

Arabasz, W. J., J. Ake, M. K. McCarter, and A. McGarr (2004). Estimation of probable maximum magnitude for coal-mining-induced seismicity in Utah—A Utah case study, *Proceedings, 34th Annual Institute, International Society of Mine Safety Professionals Critical Issues Conference*, Salt Lake City, Utah, in press.

Arabasz, W. J., S. J. Nava, M. K. McCarter, K. L. Pankow, J. C. Pechmann, J. Ake, and A. McGarr (2005). Coal-mining seismicity and ground-shaking hazard¾ A case study in the Trail Mountain area, Emery County, Utah, *Bull. Seism. Soc. Am.*, in press.

McGarr, A., J. B. Fletcher, and W. J. Arabasz (2004). Seismic hazard to the Joes Valley Dam, central Utah, due to nearby coal-mining-induced earthquakes, (abstract), *Seism. Res. Letters*, **75** (3), 444.

Pankow, K.L. and R.L. Bruhn (2004). Re-examining the transition from the Basin and Range tectonic province to the Middle Rocky Mountains tectonic province (abstract), EarthScope: Basin and Range Meeting, Tahoe, CA.

Pankow, K. L. and J. C. Pechmann (2004a). Determination of low-strain amplification factors in the Salt Lake Valley, Utah, using ANSS data (abstract), *Basin and Range Province Seismic Hazards Summit II, Program and Abstracts*, Reno-Sparks, Nevada, May16–19, 2004, 122–123.

Pankow, K. L. and J. C. Pechmann (2004b). Determination of low-strain site amplification factors in the Salt Lake Valley, Utah, using ANSS Data (abstract), *Eos, Trans. Am. Geophys. Union*, **85** (47), Fall Meet. Suppl., Abstract S043A-0974.

Pankow, K. L. and J. C. Pechmann (2004c). The SEA99 ground motion predictive relations for extensional tectonic regimes: Revisions and a new peak ground velocity relation, *Bull. Seism. Soc. Am.* **94**, 341-348.

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Sheng, J., G. T. Schuster, K. L. Pankow, J. C. Pechmann, and R. L. Nowack (2003). Coherence-weighted wavepath migration of teleseismic data (abstract), *Eos, Trans. Am. Geophys. Union* **84** (46), Fall Meet. Suppl., Abstract S11E-0344.

UUSS Staff (2003, 2004). Earthquake activity in the Utah region [summaries and maps of seismicity in the Utah region, published quarterly by the Utah Division of Comprehensive Emergency Management in *Fault Line Forum*].

Velasco, A.A., C.J. Ammon, J. Farrell, and K. Pankow (2005). Rupture directivity of the November 3, 2002 Denali earthquake determined from surface waves, *Bull. Seism. Soc. Am.*, in press.

Wald, D. J., B. C. Worden, V. Quitoriano, and K. L. Pankow (2004). ShakeMap Manual: Users Guide, Technical Manual, and Software Guide, USGS Open File Report, in review, 131 pp.

Availability of Data:

All seismic waveform data archived by the University of Utah Seismograph Stations can be retrieved from the IRIS DMC using their SeismiQuery Web tool at <*http://www.iris.washington.edu/SeismiQuery*> (delivered in a variety of formats). Alternatively, the data can be obtained upon request directly from our office (typically delivered to the user in SAC ASCII or binary format). Earthquake catalog data for the Utah region are available (1) via anonymous ftp <*ftp.seis.utah.edu/pub/UUSS_catalogs*>, (2) by e-mail request to *webmaster@seis.utah.edu*, or (3) via the Advanced National Seismic System's composite earthquake catalog, <*http://quake.geo.berkeley.edu/anss*>. See also the University of Utah Seismograph Stations homepage at <*http://www.quake.utah.edu*>. The contact person for data requests is Relu Burlacu, tel: (801) 585-7972; e-mail: *burlacu@seis.utah.edu.*

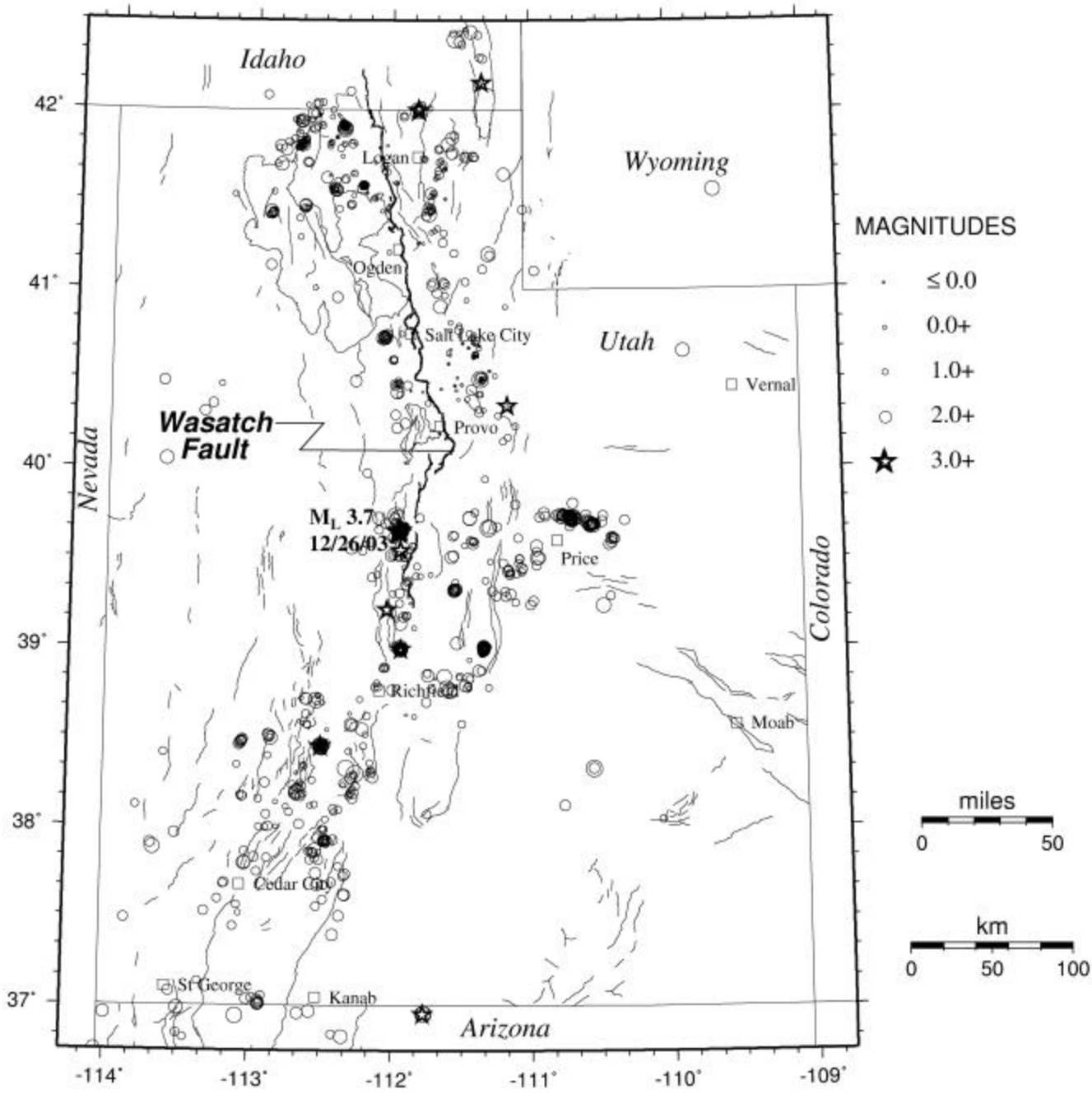

Figure 1. Earthquakes in the Utah Region, October 1, 2003 through September 30, 2004. Shocks of magnitude 3.0 and larger are plotted as stars; those less than magnitude 3.0, as circles. Base map of Quaternary faults from the Utah Geological Survey; Wasatch fault shown in bold.